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1.	Your reference	R071497PGB
2.	Patent application number *(The Patent Office will fill in this part)*	0216347.5
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Delphi Technologies, Inc PO Box 5052, Troy Michigan 48007 United States of America
	Patents ADP number *(if you know it)*	7588320001
	If the applicant is a corporate body, give the country/state of its incorporation	Delaware, United States of America
4.	Title of the invention	CONTROL METHOD
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	~~Marks & Clerk~~ ~~Alpha Tower~~ ~~Suffolk Street Queensway~~ ~~Birmingham B1 1TT~~ DAVID KELTIE ASS. FLEET PLACE HOUSE 2 FLEET PLACE LONDON EC4M 7ET U.K. 13.2.02 JHM 51/77
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6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	14
Claim (s)	3
Abstract	
Drawing (s)	6 +6

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 12 JULY 2002

12. Name and daytime telephone number of person to contact in the United Kingdom — Joanne Selina POPLE 0121 643 5881

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CONTROL METHOD

This invention relates to a control method for a fuel injection system for use in delivering fuel under high pressure to a cylinder of a compression ignition internal combustion engine.

In order to ensure that the level of emissions produced by an engine falls within an acceptable level, it is desirable to be able to control the fuel pressure at which fuel is injected to a cylinder of an engine independently of the timing of fuel delivery. It is known to achieve this by using separate valves to control the injection pressure and the timing of injection, a spill valve and a nozzle control valve respectively.

EP 0823549A1 describes a known fuel injection system of the aforementioned type, illustrated schematically in Figure 1. The system includes an injection nozzle, referred to generally as 10, including a valve needle 12, which is urged towards a valve needle seating by a spring load 13. The valve needle 12 is engageable with the seating to control fuel delivery between a nozzle delivery chamber (not shown) and an injection nozzle outlet to the engine. The system also includes a pump arrangement including a pumping plunger 14, which is driven by a mechanical drive arrangement (not shown) to pressurise fuel within a pump chamber 16 in communication with the nozzle 10 through a high pressure supply line 18. A spill control valve 20 is operable to control communication between the pump chamber 16 and a low pressure drain (not shown), and hence controls the timing of commencement of fuel pressurisation within the pump chamber 16. A nozzle control valve 22 is operable to control communication between a pressure control chamber 24 and the low pressure drain, and is operable to control the

timing of commencement of injection. If the spill control valve 20 is open to low pressure, plunger movement causes fuel to be drawn into and spilled back through the valve 20 to low pressure, but if the spill valve 20 is closed, plunger movement in a direction to reduce the volume of the pump chamber 16 causes fuel pressure within the pump chamber 16 to increase. If the nozzle control valve 22 is closed, fuel pressure within the control chamber 24 is increased due to a continuous supply of fuel from the high pressure supply line 18, but when the nozzle control valve 22 is opened, the control chamber 24 communicates with the low pressure drain and fuel pressure within the control chamber 24 is reduced. When the desired fuel pressure has been reached within the pump chamber 16, the nozzle control valve 22 can therefore be opened to relieve fuel pressure in the control chamber 24, causing the valve needle 12 to be lifted under a hydraulic force, away from its seating, to commence injection.

The mechanical drive arrangement for the plunger 14 typically includes a driven cam (not shown) and a roller which rides over the surface of the cam as it rotates. The roller is cooperable with a drive member coupled to the plunger, which applies a drive force to the plunger 14 to perform a pumping stroke during which the plunger 14 is driven in a direction to reduce the volume of the pump chamber 16. As the roller rides over the cam lobe, a return spring serves to drive the plunger return stroke, during which the plunger moves in a direction to increase the volume of the pump chamber.

It has been observed that the drive train components tend to separate at the end of injection, and as the components are subsequently brought into contact an undesirable level of mechanical noise may be generated.

It is one object of the present invention to provide a control method for a fuel injection system generally of the aforementioned type, in which the problem of mechanical noise is alleviated.

There is also an increasing need in the automotive industry to reduce emissions levels, for example NOx and smoke levels, both for environmental purposes and to improve engine efficiency, and it is a further object of the invention to provide a control method which provides beneficial emissions levels.

According to a first aspect of the present invention, there is provided a control method for a fuel injection system having a spill valve, a nozzle control valve and a valve needle which is engageable with a seating to control fuel injection, the method comprising:

applying a first drive current signal to the spill valve to move the spill valve into a closed state and applying a second drive current signal to the nozzle control valve to move the nozzle control valve to an open state, thereby to lift the valve needle from the seating to initiate a main injection of fuel, and

modifying the first drive current signal applied to the spill valve so as to move the spill valve from the closed state to an open state during a spill valve opening period and modifying the second drive current signal applied to the nozzle control valve to move the nozzle control valve from the open state to a closed state within the spill valve opening period, so as to urge the valve needle towards its seating to terminate the main injection of fuel.

One advantage of the present invention is that the valve needle is caused to close whilst the spill valve is moving from its closed state to its open state. The rate of flow of fuel through the spill valve to low pressure (i.e. the "spill rate"), and thus the rate of decrease in injection pressure at the end of injection is therefore reduced due to the reflected or positive pressure wave generated by closure of the valve needle. Thus, mechanical noise generated as a result of drive load overshoot, and separation and recontact of the associated pump drive components, can be reduced or avoided.

In a preferred embodiment, the first drive current signal is switched off to move the spill valve to its open state at a time of between 0.05 and 2 milliseconds before the second drive current signal is switched off to move the nozzle control valve to its closed state, and more preferably the first drive current signal is switched off between 0.1 and 1 millisecond before the second drive current signal is switched off. This particular relative timing relationship between actuation of the spill and nozzle control valves to terminate an injection event is found to provide a suitable compromise between (i) a lower rate of decrease of injection pressure at the end of injection to minimise mechanical noise from the pump drive components (ii) a low enough fuel delivery quantity at the end of injection to minimise smoke emission levels and (iii) a high enough injection pressure to prevent nozzle blowback.

According to a second aspect of the present invention there is provided a control method for delivering a main injection of fuel followed by a post injection of fuel, the method comprising:

actuating a spill valve and a nozzle control valve to initiate the main injection of fuel,

terminating the main injection of fuel by (i) actuating the spill valve to move into an open state at a first time and (ii) actuating a nozzle control valve to move into a closed state at a second time,

subsequently actuating the spill valve to move from its open state to a closed state at a third time, and

initiating the post injection of fuel by actuating the nozzle control valve to move into an open state, whereby the difference between the first and third times is selected to provide a relatively high pressure post injection of fuel so as to reduce smoke emissions levels.

It has been found to be desirable to provide a main injection of fuel followed by a post injection of fuel to improve emissions.

The present invention provides an advantage over methods whereby only the nozzle control valve is activated to initiate a main and a post injection of fuel, for which structural problems arise due to stresses within the apparatus caused by extremely high pressure levels.

In a preferred embodiment, the spill valve is actuated to move between its open and closed states by modifying a spill valve drive current signal. Preferably, the relative timing between opening and closure of the spill valve is selected to ensure the post injection pressure is at least 1700 bar.

In a further preferred embodiment, the relative timing is selected to ensure the post injection pressure is at least 2000 bar.

It will be appreciated that preferred features of the first aspect of the invention are equally applicable to the second aspect of the invention.

The invention will now be described, by way of example only, by reference to the accompanying drawings in which:

Figure 1 is a schematic illustration of a known fuel injection system,

Figure 2 is a schematic graph to illustrate the drive load characteristic of a known control method for the fuel injection system in Figure 1, and for which the origin of mechanical noise is identifiable,

Figure 3 is a schematic graph to illustrate the drive load characteristic of an alternative known control method for the fuel injection system in Figure 1, and for which the origin of mechanical noise is also identifiable,

Figure 4 shows (a) the drive current signal for the spill valve, (b) spill valve lift, (c) the injection pressure/drive load characteristic (d) the drive current signal for the nozzle control valve (e) nozzle control valve lift and (f) valve needle lift, for a control method in accordance with the present invention,

Figure 5 shows test results for (a) cylinder pressure (b) injection pressure and (c) needle lift using the control method in Figure 4,

Figure 6 shows further test results for (a) cylinder pressure (b) injection pressure (c) needle lift (d) spill valve drive current signal and (e) nozzle control valve drive current signal for an alternative control method of the present invention, and

Figure 7 shows a table of results corresponding to Figure 6 to illustrate the smoke emissions benefits obtained using the control method illustrated in Figure 6.

Figures 2 and 3 show the drive load characteristic during an injection event using one known control method for the fuel injection system in Figure 1. Between times t1 and t2, the spill valve 20 is closed and fuel pressure within the pump chamber 16 increases. Between times t2 and t3, the nozzle control valve 22 is opened to reduce fuel pressure within the control chamber 24, and the valve needle 12 starts to lift from its seating due to high fuel pressure within the delivery chamber which acts against the spring load 13, and injection commences. Between times t3 and t4 the nozzle control valve 22 is closed, and the flow of high pressure fuel from the supply line 18 into the control chamber 24 serves to urge the valve needle into engagement with its seating (at time t4) to terminate injection.

Between times t4 and t5, pressurisation of the control chamber 24 continues due to the continuous flow of high pressure fuel from the supply line 18, and the mechanical drive load increases. At time t5, the spill valve 20 is opened, so that fuel pressure within the pump chamber 16 and the supply line 18 is reduced, and a point is reached, just prior to time t6, at which the drive load is negative (i.e. herein referred to as "drive load overshoot"). At time t6 in the cycle the pump components are therefore caused to separate. Mechanical

noise generated as a result of the drive components re-contacting one another as the drive load oscillates about zero (between times t6 and t7) is undesirable.

Using this injection control method, it will be appreciated that the end of injection is initiated by actuating the nozzle control valve 22 to increase pressure within the control chamber 24.

An alternative control method will now be described with reference to Figure 3, which shows the drive load during an injection cycle in which injection is terminated by actuating the spill valve 20. As described previously, between times t1 and t2 the spill valve 20 is closed and fuel pressure within the pump chamber 16 increases. Between times t2 and t3 the nozzle control valve 22 is opened to reduce fuel pressure within the control chamber 24, and the valve needle 12 starts to lift from its seating to commence injection. At time t3, the spill valve 20 is opened to reduce the pressure of fuel delivered to the nozzle through the supply line 18, so that the force acting on the needle 12 is reduced and the valve needle 12 is urged against its seating by the nozzle spring load 13. There is a rapid decrease in drive load when the spill valve 20 is opened and, due to the relatively high rate of flow of spilled fuel to low pressure, the drive load overshoots (time t4). The valve needle is seated at time t3A. As described previously, the drive load overshoots until at time t4 the drive train components are caused to separate. Subsequent recontact of the drive train components (between time t4 and time t5) gives rise to mechanical noise, which continues as the drive load oscillates about zero between times t4 and t6, and possibly beyond.

One aspect of the present invention, referred to as "synchronous end of injection" addresses the aforementioned problem and alleviates the disadvantageous effects of mechanical noise by near-synchronising operation of the spill valve 20 and the nozzle control valve 22 to terminate injection. Figure 4 shows (a) the drive current signal for the spill valve 20, (b) the spill valve lift, (c) the drive load (as shown in Figures 2 and 3), (d) the drive current signal for the nozzle control valve 22, (e) the nozzle control valve lift and (f) the valve needle lift, for the synchronous end of injection method. Figure 5 shows measurements of (a) cylinder pressure, (b) injection pressure and (c) valve needle lift using the synchronous end of injection method of Figure 4.

At the start of an injection cycle, a drive current signal 30 for the spill valve 20 is switched on and ramps between times t1 to t2 to a first relatively high current level. The spill valve 20 is moved into its fully closed state at time t3, and fuel pressurisation within the pump chamber 16 commences, as illustrated in Figure 4(c). At time t3, a drive current signal 40 is applied to the nozzle control valve 22 to lift (open) the nozzle control valve 22, thereby causing fuel pressure within the control chamber 24 to be reduced until at time t4 the valve needle 12 starts to lift from the seating, against the spring load 13, to commence injection.

Termination of the fuel injection event is achieved in the following manner. At time t5, the drive current signal 30 is switched off and a short time later (time t8) the spill valve 20 starts to move towards its open state. At time t7, just after the drive current signal 30 for the spill valve 20 is switched off, a drive current signal 40 for the nozzle control valve 22 is switched off and the nozzle control valve 22 starts to move to its closed state (time t8) to re-

establish high fuel pressure within the control chamber 24. The near synchronisation of opening of the spill valve 20 and closure of the nozzle control valve 22 to terminate injection (time t9) has the effect that the drive load decays to zero, but that oscillations about zero and drive load overshoot are avoided. This advantageous effect is illustrated in Figure 4(c) between times t9 and t10.

Immediately after injection has been terminated, between times t9 and t10, the rate of flow of fuel through the open spill valve 20 to low pressure will be reduced compared to that using the conventional methods (Figure 2 and 3), due to the additional positive (reflected) pressure wave generated upon closure of the valve needle 12 which occurs as the spill valve 20 is still moving towards its fully open position. It is therefore an important feature of the invention that at the moment the valve needle 12 actually closes (time t9) at the end of pressure decay, the spill valve 20 is still moving towards its open position (see Figure 4(b)) i.e. during spill. By controlling the spill and nozzle control valves 20, 22 such that they are phased in this manner, the problems associated with drive load overshoot, and hence mechanical noise, may be alleviated. In practice, the optimum relative timing between actuation of the valves will be determined by parameters of the system, such as actuator delays and pipe lengths and volumes. Conveniently, the relative timing of switching of the valves 20, 22 to terminate injection may be determined by reference to pre-calibrated data, using look up tables or data maps.

In an alternative embodiment, the rate of spill through the open spill valve 20 to terminate injection may be modified further by reconfiguring certain flow passages/restrictions, thereby further reducing the rate of decay of pressure

between times t9 and t10 and, hence, further reducing mechanical noise generated by the drive train components at the end of injection.

A further aspect of the invention permits the smoke emissions level to be reduced at the end of an injection event by selecting particular drive current signal timings for the spill valve 20 and the nozzle control valve 22. It has been found that for lower values of needle lift (e.g. at the end of injection) the associated fuel spray form is less desirable. Thus, by minimising the fuel quantity and the injection pressure at such lower lift values, the smoke level in the exhaust stream can be reduced. It is important, however, that the injection pressure is maintained at a sufficiently high level during closure of the valve needle to avoid blowback of the cylinder gases into the nozzle. Additionally, as described previously, it is beneficial to reduce the rate of decrease of injection pressure (times t9 to t10 in Figure 4(c)) at the end of injection so as to reduce the effects of mechanical noise generated by the drive train components. To compromise between achieving a relatively low smoke emission level, no nozzle blowback and low mechanical noise, it has been found that the spill valve drive current signal 30 should be switched off (i.e. to open the spill valve 20) between 0.1 a 1 millisecond before the nozzle control valve drive current signal 40 is switched off to close the nozzle control valve 22 and, thus, seat the valve needle 12.

It is also desirable in some operating conditions for a pilot injection of fuel to be delivered to the engine, prior to a main injection, or for a main injection of fuel to be followed by a post injection. For example, the use of a pilot injection prior to a main injection can be used to reduce combustion noise, and the use of a post injection shortly after a main injection has combustion benefits for soot reduction.

In order to optimise the combustion benefits of applying a main injection followed by a post injection, it is desirable to vary the injection pressure for the post injection of fuel such that the post injection pressure is high. This may be achieved using the method illustrated in Figure 6, which shows the drive current signals 30, 40 for the spill valve 20 and the nozzle control valve 22 respectively. The injection pressure is illustrated by three traces 50A, 50B and 50C, having decreasing peak injection pressure values. The bottom trace in Figure 6 illustrates valve needle lift, and shows a main injection (60A) of fuel followed by a post injection (60B) within the same injection cycle.

To terminate the main injection of fuel prior to the post injection, the spill drive current signal 30 is switched off (corresponding to time t8, as shown in Figure 4(b)) to move the spill valve 20 towards its open state. The nozzle control valve 22 is in its closed state at the end of the main injection event. It will be appreciated that the drive current signals 30, 40 in Figure 6 are shown to be switched negative to activate the respective valve, but equally the electrical connections to the valves may be configured such that the drive current signals 30, 40 are switched positive to actuate the respective valves.

To initiate the post injection of fuel, the drive current signal 30 for the spill valve 20 is switched on to reduce the rate at which fuel can escape from the supply line 18 and pump chamber 16 to low pressure, and fuel pressure in the nozzle delivery chamber starts to increase as pumping continues. When the post injection of fuel is required, the drive current signal 40 is switched on to move the nozzle control valve 22 into its open state to relieve fuel pressure within the control chamber 24, and the valve needle 12 is caused to lift again.

As can be seen from the three traces 50A, 50B, and 50C, the period of time after termination of the main injection at which the drive current signal 30 for the spill valve 20 is switched on to cause the valve 20 to start to close determines the rate of decay of fuel pressure between the main injection and the post injection, and thus determines the injection pressure for the post injection event. It has been found that there are considerable benefits for emissions if the post injection pressure is high, and by careful selection of the relative timing between opening of the spill valve 20 to terminate the main injection event and closure of the spill valve 20 for the post injection event, a high pressure post injection of fuel can be achieved. By way of example, Figure 7 shows numerical test results corresponding to Figure 6, from which it can be seen that the level of smoke in the exhaust emissions is considerably reduced for higher post injection pressures. For a post injection pressure greater than 1700 bar (50B), the level of emitted smoke is greatly reduced compared with a lower post injection pressure (50C), and a post injection pressure in excess of 2000 bar (50A) improves the smoke emissions level further. It can also be seen from Figure 6 that only for trace C is the injection pressure reduced to substantially zero between the main and post injections of fuel.

It has previously been proposed to achieve a main injection of fuel followed by a post injection of fuel by operating only the nozzle control valve 22. Using this technique, the spill valve 20 remains closed between the main and the post injection and instead just the nozzle control valve 22 is opened to relieve fuel pressure in the control chamber 24 to initiate the post injection of fuel, and is closed at the end of post injection to re-establish high fuel pressure in the control chamber 24. As a consequence of using this method, however, the level of injection pressure in the post injection is not under

independent control and may be excessively high, especially if wider separation times between the main and post injection events are required. The benefit of the present invention is that the injection pressure can be made independent of the separation between the main and post injection.

Although the fuel system shown in Figure 1 shows the spill valve 20 and the nozzle control valve 22 arranged remotely from one another, the invention is equally applicable to unit pump injection systems in which the spill and nozzle control valves are arranged within a common housing, or in which the spill valve and the nozzle control valve functions are under the control of a common actuator.

CLAIMS

1. A control method for a fuel injection system having a spill valve, a nozzle control valve and a valve needle which is engageable with a seating to control fuel injection, the method comprising:

applying a first drive current signal to the spill valve to move the spill valve into a closed state and applying a second drive current signal to the nozzle control valve to move the nozzle control valve to an open state, thereby to lift the valve needle from the seating to initiate a main injection of fuel, and

modifying the first drive current signal applied to the spill valve so as to move the spill valve from the closed state to an open state during a spill valve opening period and modifying the second drive current signal applied to the nozzle control valve to move the nozzle control valve from the open state to a closed state within the spill valve opening period, so as to urge the valve needle towards its seating to terminate the main injection of fuel.

2. The control method as claimed in Claim 1, wherein the first drive current signal is switched off to move the spill valve to its open state at a time of between 0.05 and 2 milliseconds before the second drive current signal is switched off to move the nozzle control valve to its closed state.

3. The control method as claimed in Claim 2, wherein the first drive current signal is switched off between 0.1 and 1 millisecond before the second drive current signal is switched off.

4. The control method as claimed in any of Claims 1 to 3, wherein the

first drive current signal is switched on to move the spill valve to the open state.

5. The control method as claimed in any of Claims 1 to 4, wherein the second drive current signal is switched on the move the nozzle control valve to the open state.

6. A control method for delivering a main injection of fuel followed by a post injection of fuel, the method comprising:

actuating a spill valve and a nozzle control valve to initiate the main injection of fuel,

terminating the main injection of fuel by (i) actuating the spill valve to move into an open state at a first time and (ii) actuating a nozzle control valve to move into a closed state at a second time,

subsequently actuating the spill valve to move from its open state to a closed state at a third time, and

initiating the post injection of fuel by actuating the nozzle control valve to move into an open state, whereby the difference between the first and third times is selected to provide a relatively high pressure post injection of fuel so as to reduce smoke emissions levels.

7. The control method as claimed in Claim 6, whereby the spill valve is actuated to move between its open and closed states by modifying a spill valve drive current signal.

8. The control method as claimed in Claim 7, wherein the relative timing between opening and closure of the spill valve is selected to ensure the post injection pressure is at least 1700 bar.

9. The control method as claimed in Claim 8, wherein the relative timing between opening and closure of the spill valve is selected to ensure the post injection pressure is at least 2000 bar.

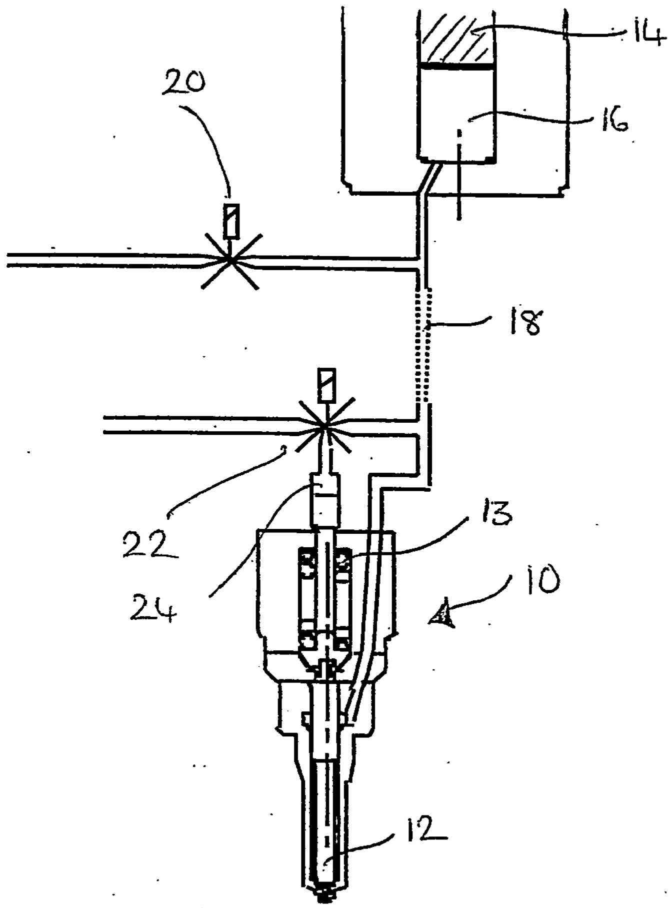


FIGURE 1
PRIOR ART

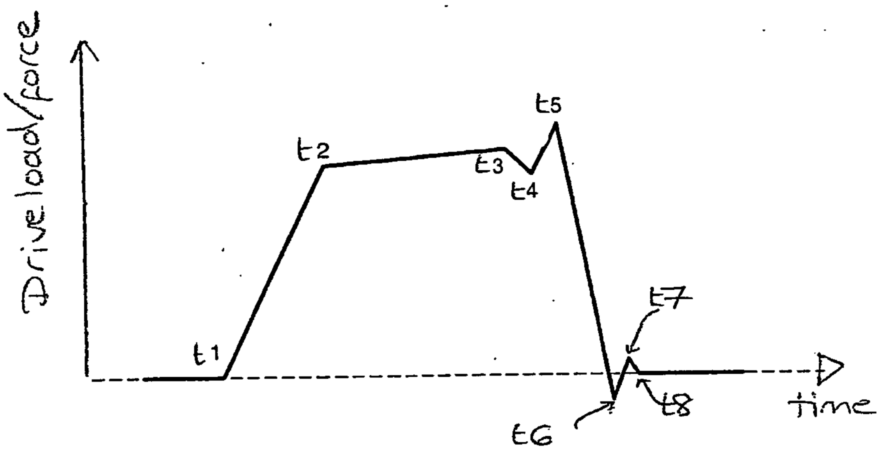


FIGURE 2

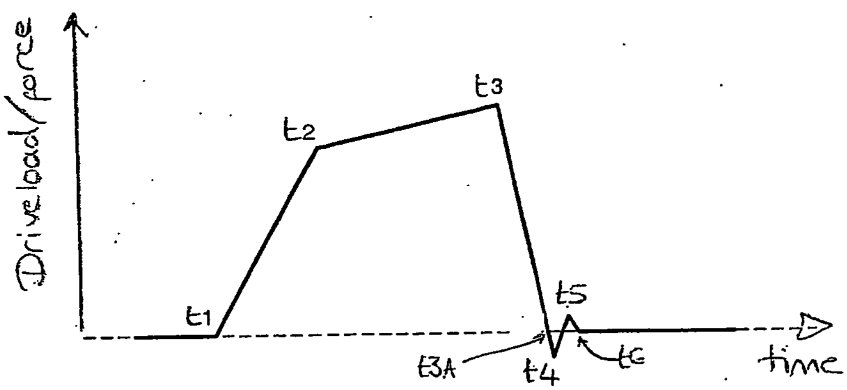
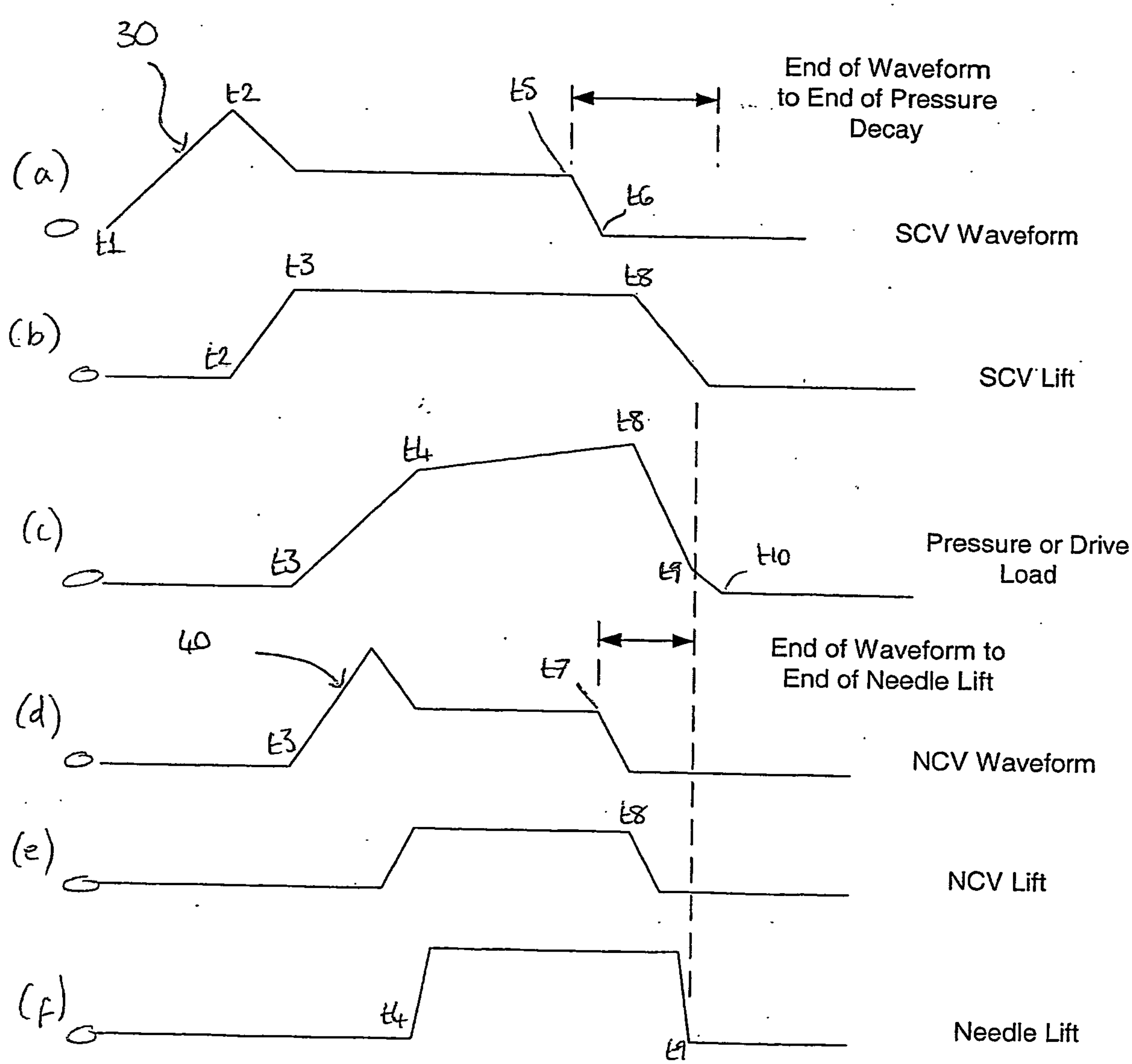


FIGURE 3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SCV Lift
t8
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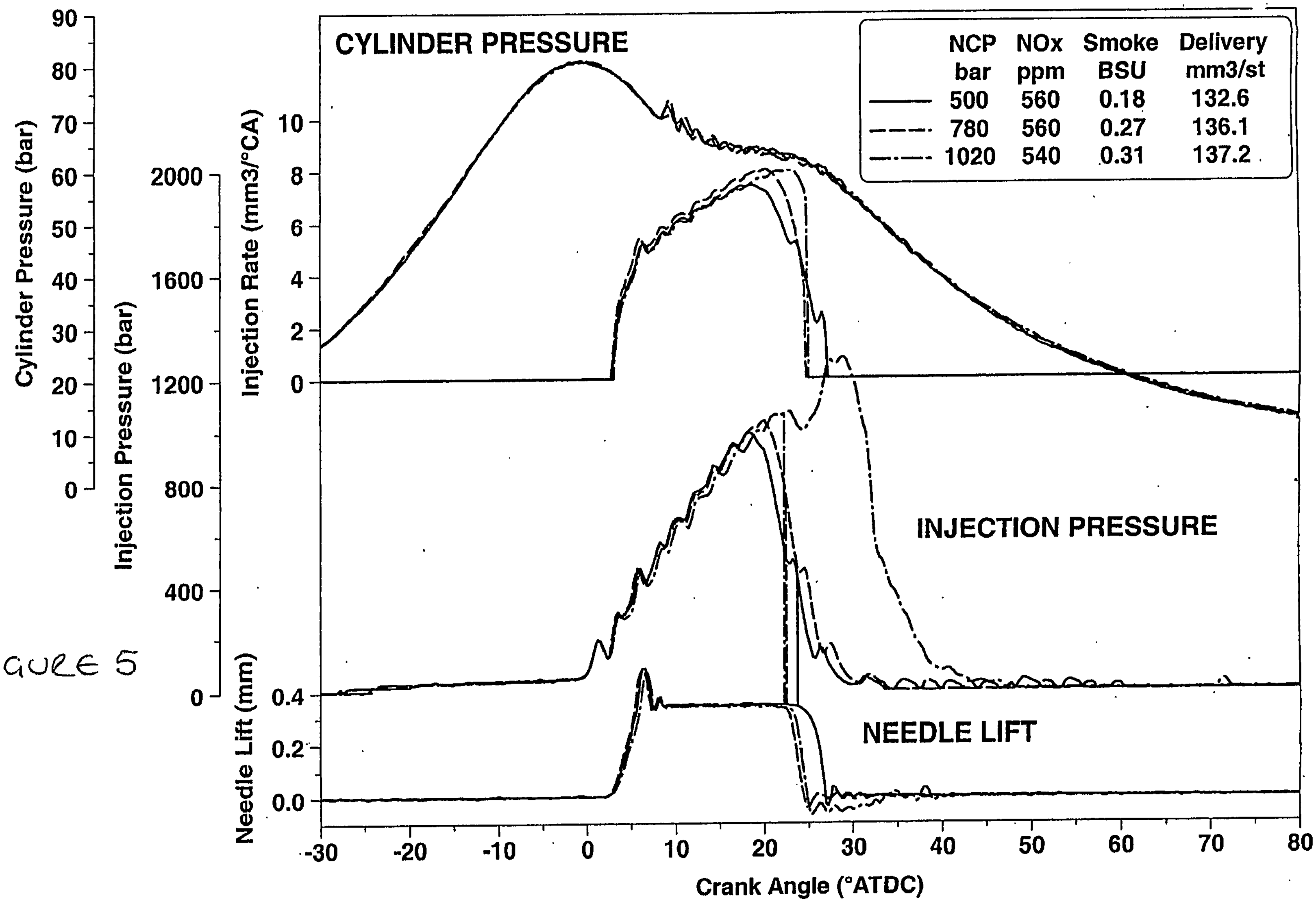
FIGURE 4



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INJECTION PRESSURE
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Smoke BSU
Delivery mm3/st
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780 560 0.27 136.1
1020 540 0.31 137.2
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Needle Lift (mm)
Crank Angle (°ATDC)
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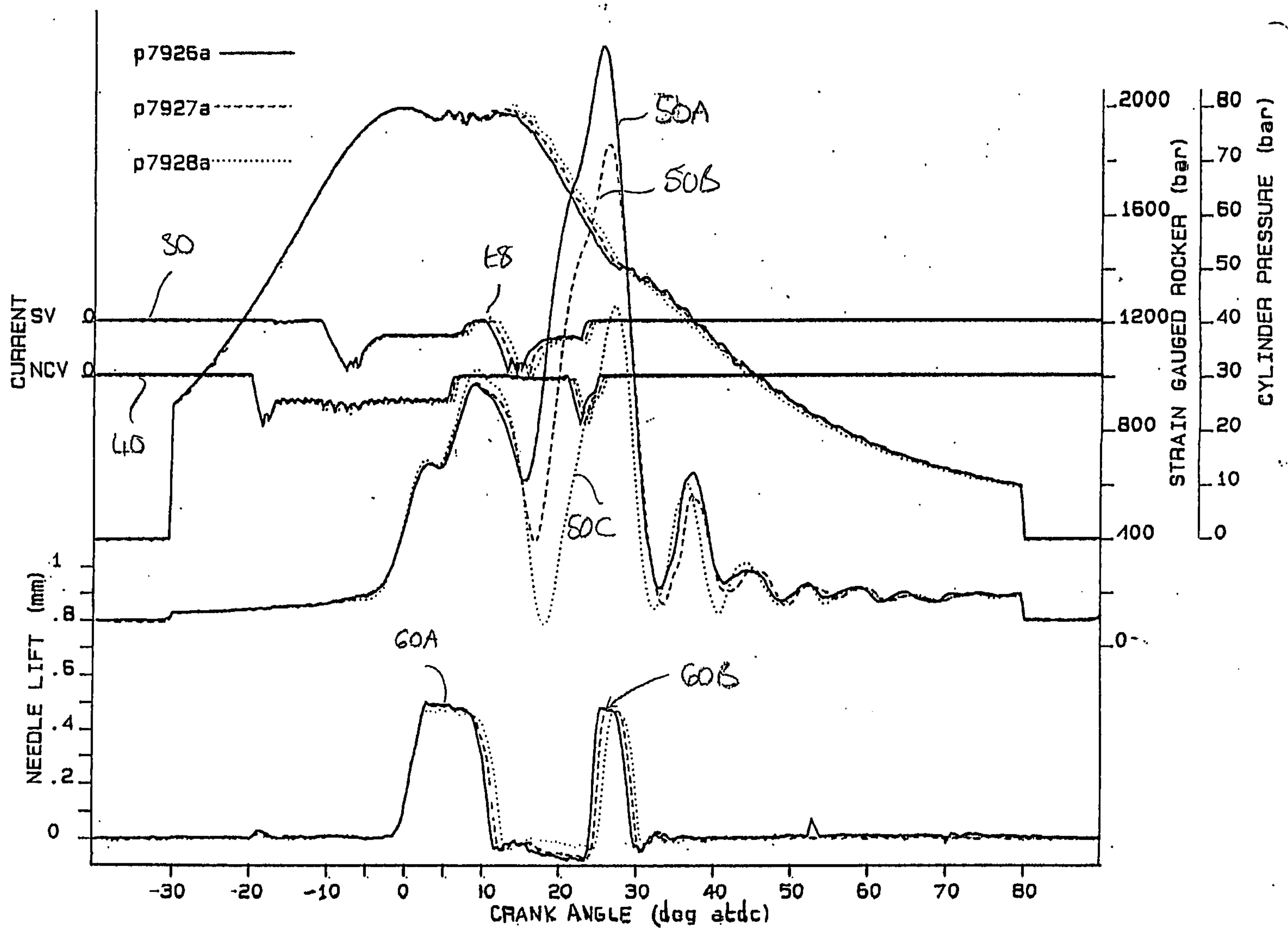
FIGURE 5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70
80
CRANK ANGLE (deg atdc)

FIGURE 6

	Injection diagram	NOx ppm	Smoke FSN	Delivery mm3/st
———	High pressure post	552	0.17	138.5
– – –	Med. pressure post	552	0.23	140.2
·······	Low pressure post	551	0.48	136.7

FIGURE 7